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EVALUATION OF EVAPORATIVE LOSSES OF FOG WATER COLLECTED WITH THE CALTECH ACTIVE FOG WATER SAMPLER

Report No. 91-173-K

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ABSTRACT

The performance of the CalTech active fog water sampler, in particular the effect of evaporative losses on apparent conductivity of fog water, was investigated under controlled laboratory conditions. The collected fog water was found to have slightly enhanced conductivity (about 20%, not the factor of 3-4 times suggested by some). The experimental conditions used in these tests were more demanding on evaporative effects than achieved in actual field conditions due to lower test relative humidity and higher test temperature. The test results support the past conductivity field data in that a significant bias through evaporative effects was not observed. A brief description of some of the processes involved during a fog episode is also presented.

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1.0 INTRODUCTION

The Caltech active fog water sampler has been used to sample winter fogs in connection with the insulator icing problem/1/. Fogs with conductivities as high as 1000 μS/cm have been collected/2/. Such high conductivities are not unexpected, given measurements elsewhere/2/, and the known physics and chemistry of fogs. Fog water conductivities obtained in Southern Ontario were typically 3 to 4 times higher than in rain water collected during the same storm. This higher conductivity is generally explained by the interaction of the fog droplet with the surrounding air, the latter being more contaminated than air at cloud level. Evaporation and condensation processes further change the liquid water content of the fog. The reported higher conductivities of fog water raised questions within Hydro about sampling artifacts which might bias the results towards high values. It was necessary, then, to insure that the high conductivities observed in the field were reasonable and not an artifact of the collection technique.

Fog water is collected by inertial impaction of fog droplets on a screen of Teflon strings. The collected fog water conductivity will depend on the characteristics of the "fog system" (liquid water content, the droplet size distribution, the saturation of air with water vapour, the temperature and the wind velocity). The sample collection step, too, could influence the observed fog water conductivity. In particular, evaporation of water while it resides on the screens, has been suggested as a source of error. To evaluate the effect of any evaporative losses by the collection process artificial fogs of known conductivity were collected under controlled conditions. This report outlines the performance conditions and results.

2.0 EXPERIMENTAL

2.1 Equipment

The Caltech active fog water sampler was evaluated under controlled conditions in the laboratory by setting up a rig which allowed air to be humidified and cleaned of any particulate matter residues, before a fog of known conductivity was generated and sampled by the collector. The operation was closed-loop in that the outlet from the collector was returned to the humidification chamber, in order to minimize deviations from steady state temperature and humidity.

The active fog water sampler was fitted with an inlet filter, humidity control box , fog nozzle and RH/temperature probes as shown in Figure 1. The filter used was a 2' X 2' HEPA (high efficiency particulate aerosol) filter. The performance of the filter in the experimental set up was confirmed (99.9%) using a TSI model 3020 condensation nucleus counter. The relative humidity and temperature were monitored using two Rotonics MP100 probes interfaced with a Campbell Scientific CR10 datalogger and IBM AT system. The MP100 probes, the same probes used in the freezing rain field studies, utilize thin film variable capacitance technology to measure relative humidity directly and a platinum RTD for

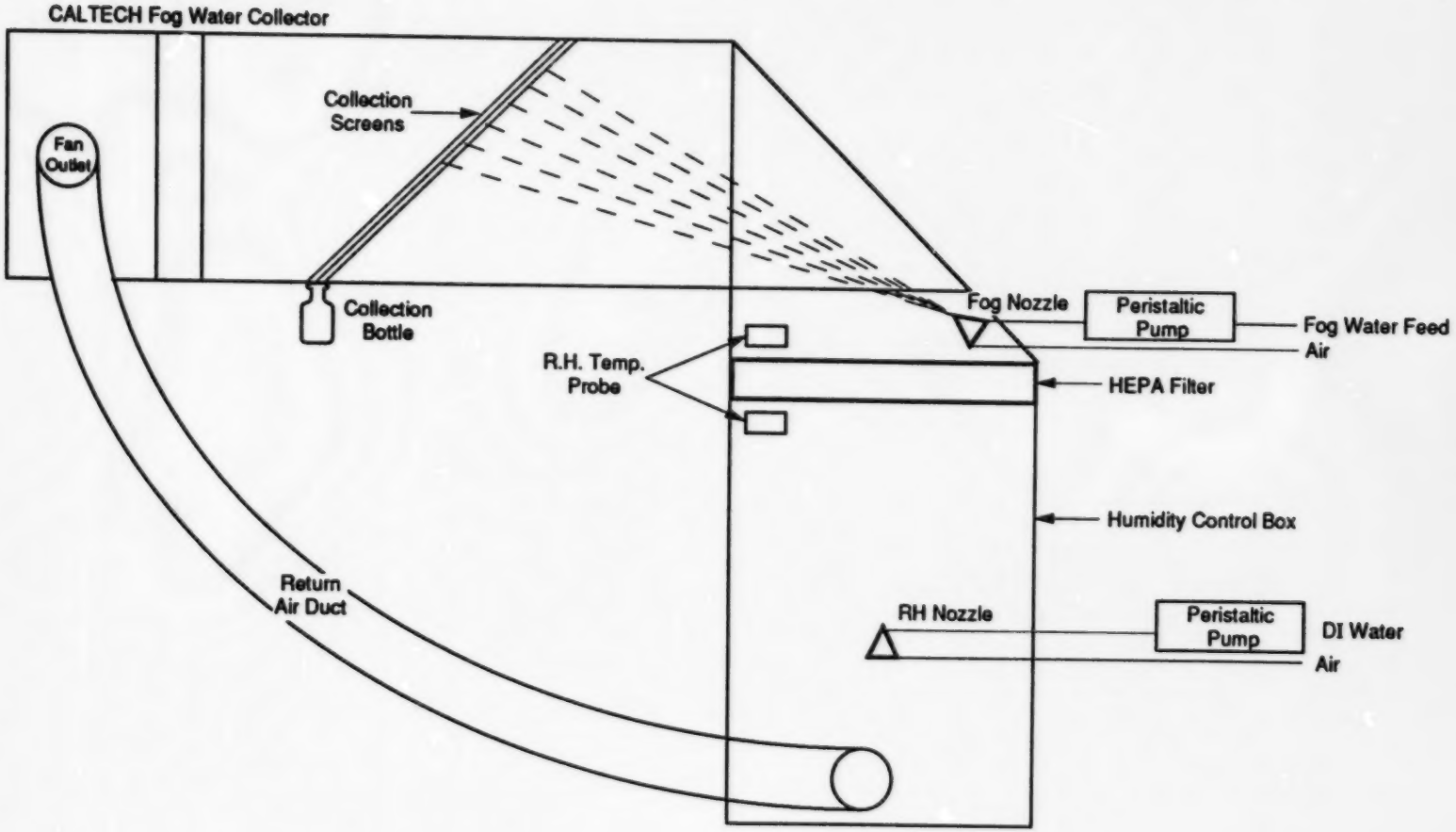


FIGURE 1

TEST APPARATUS

temperature. The fog was generated using a 2 mm Turbotak Caldyn nozzle and was expected to produce a mean aerosol diameter of 9 to 12 μm/3/. This size distribution was not confirmed in this study. The humidity control box consisted of a "Spraying Systems" nozzle in a 2' X 2' X 4' plastic enclosed box. This box also housed one of the RH/temperature probes, the collector return air vent and a room air make-up vent. A Balston air filtration unit was used on air supply to the nozzles. (Attempts to have the air supply to the fog nozzle humidified by passing through a stainless steel bubbler containing deionised water failed). Two variable speed peristaltic pumps were used for the water supply to the nozzles. Conductivity was measured with a Radiometer CDM83 conductivity meter and Radiometer Type CDC 314 (cell constant 0.316 cm) flow through cell.

2.2 Experimental Conditions

The experimental set up is shown in Figure 1. The relative humidity in the test system was raised to between 80 and 90% by operating the Spraying Systems nozzle with deionized water, with the collector operating. After the desired relative humidity was achieved, usually within 10 minutes, the fog nozzle was started with water of a known conductivity and samples were collected every 5 to 10 minutes. Three collection screens were used in all tests except for test J where one screen was used. The fog water consisted of potassium chloride or ammonium sulphate solutions. All conductivities were measured at 25°C immediately after collection. The conditions used for each test and the results obtained are given in Table 1.

3.0 RESULTS AND DISCUSSION

3.1 Test Results and Discussion

The results (see Table 1) show that the conductivity of the collected water is slightly enhanced with a good linear relationship, $y = 1.177\ x$, $r^2 = 0.993$, with the intercept forced through the origin (and $y = 1.190\ x - 5.272$, $r^2 = 0.997$, without forcing the intercept through the origin) from 50 to over 500 μS/cm. These results are presented graphically in Figure 2. Time resolved data for one of the tests are also presented in Figure 3.

The test conditions used may be considered more challenging than field conditions because of the lower relative humidity levels (as low as 81%) and higher temperatures (as high as 23°C) of the tests. Low relative humidity and high temperature promote evaporation. On the other hand, the larger liquid water content used would have resulted in a less challenging test of the evaporation effect. A different type of nozzle would be required for much lower levels of liquid water content. (It should be noted, however, that the same increase ($y = 1.2\ x$) was observed throughout the range (0.7 - 3.3 g/m^3) of liquid water contents used.) It may also be possible to attribute the observed small increase in conductivity to evaporative losses at or within the fog nozzle which was operated with dry air.

TABLE 1

TEST CONDITIONS AND RESULTS

	SALT	RH %	TEMP °C	SOURCE FOG CONDUCTIVITY µS/cm	COLLECTED FOG CONDUCTIVITY µS/cm	LWC g/m^3
A	KCl	88	1	50.9	54.1	2.4
B	KCl	88	21	206	208	3.3
C	KCl	81	21	56.4	61.5	3.2
D	KCL	87	21	51	59.5	2.1
E	KCL	91	23	50.1	65.9	0.75
F	KCL	91	23	50	61.8	0.94
G	KCl	91	23	490	542	1.11
H	KCl	90	21	476	578	0.84
I	$(NH_4)_2SO_4$	93	22	515	636	0.69
J	$(NH_4)_2SO_4$	93	23	515	607	0.70

3.2 Condensation and Evaporation Processes During a Fog Episode

The condensation and evaporation processes that occur during fog episodes complicate the collection step. During the formation or early stages of a fog period the collected droplets are not in thermodynamic balance with the surrounding air. The microphysical processes that occur during the course of a fog episode become important when the collected fog droplets are not immediately removed, such as with passive fog collectors.

Activated fog droplets are not in a stable equilibrium with their environment and react sensitively to the slightest changes in temperature and relative humidity (Kohler curve). Before an aerosol particle of a given size reaches its activation diameter, its size is in a stable equilibrium with the environmental air and the slightest changes in relative humidity or temperature cause small changes in particle size. A particle will become activated and become a condensation nucleus if a certain critical supersaturation is reached. With a higher supersaturation than that corresponding to the actual equilibrium, the droplet can grow indefinitely by condensation. With a lower supersaturation the droplet evaporates until a stable equilibrium is reached with a size smaller than the activation diameter.

FIGURE 2

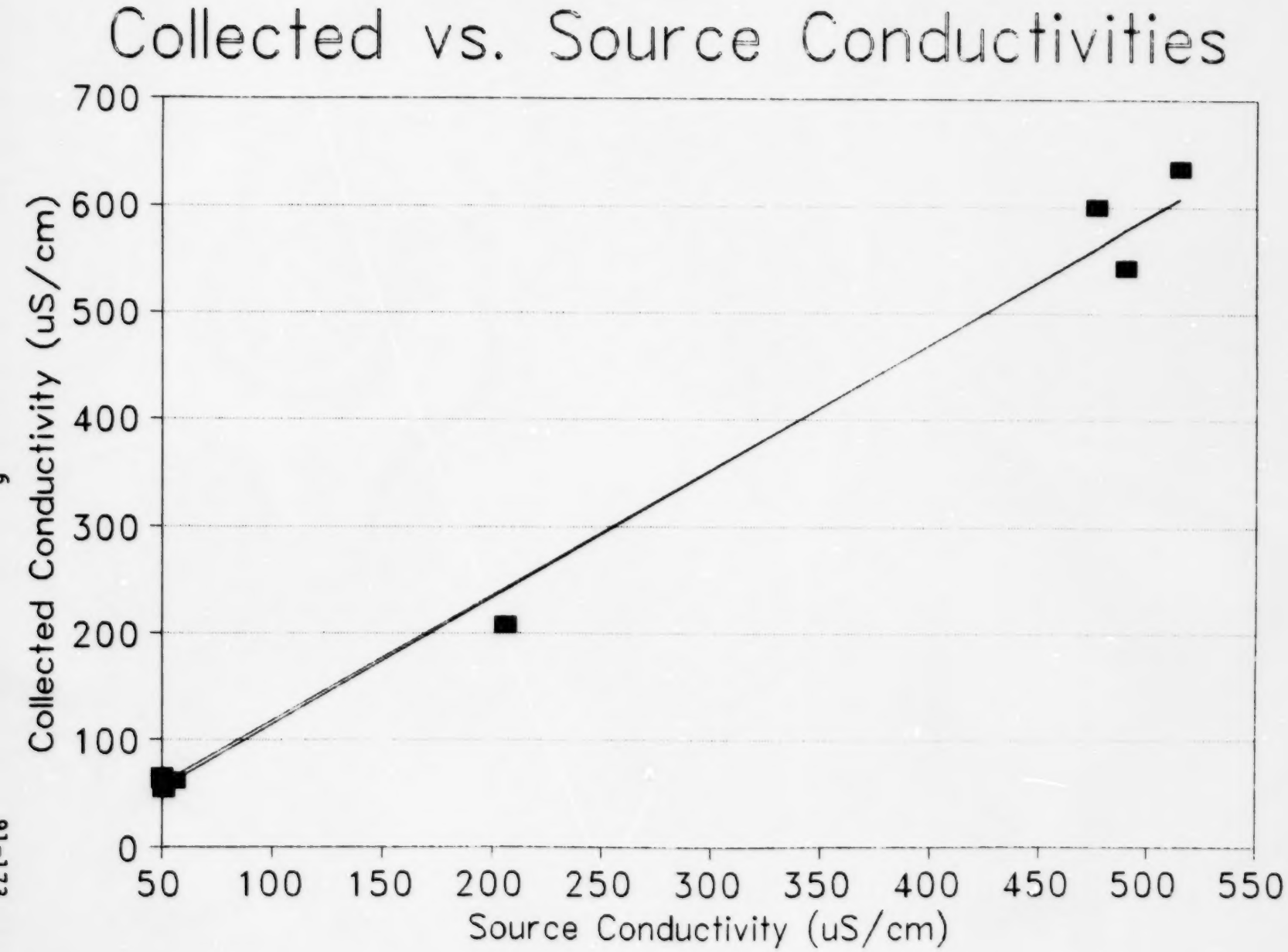
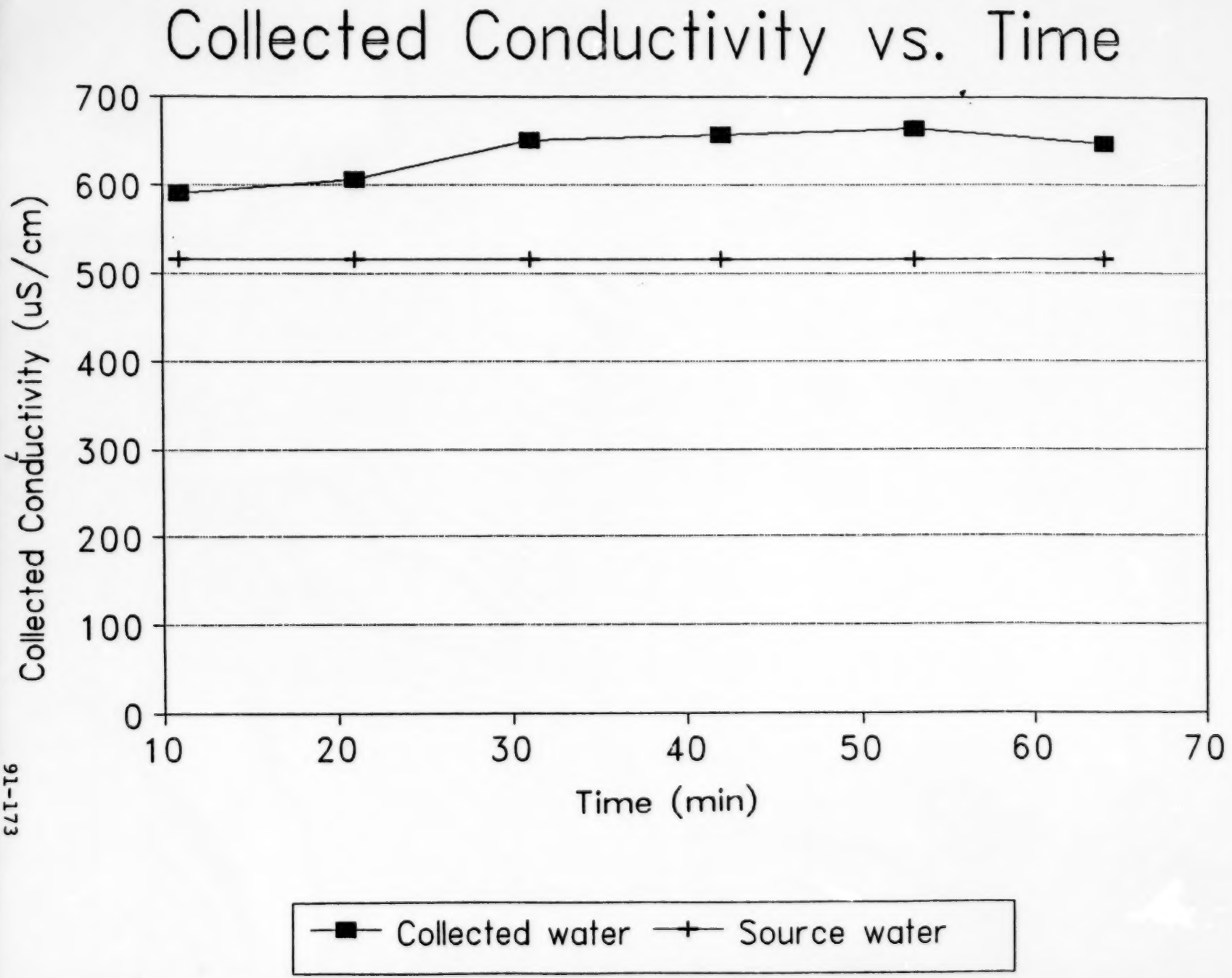

Collected vs. Source Conductivities
Collected Conductivity (uS/cm)
0
100
200
300
400
500
600
700
50
100
150
200
250
300
350
400
450
500
550
Source Conductivity (uS/cm)

FIGURE 3



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The relative humidity of fog (super and under saturated) gains in importance when the collected fog droplets are not immediately removed, such as with passive collectors. The occurrence of condensation and evaporation processes changes the sample concentration and the coupled diffusiophoresis may change the relative sample composition if the collected droplets are not transported quickly enough out of the air stream to the collecting bottle. (Quickly enough means that the resting period of the droplet on the string must be short in comparison to the time that the liquid water content of the fog air changes by means of increased condensation or by evaporation.) These microphysical processes would be more evident on samples collected during the early (formation) stages or late stages (breakup) of a fog episode with the presence of the lower (<80%) relative humidity as a driving force. As a rule field samples for the freezing rain study are not collected during such periods.

4.0 CONCLUSIONS AND RECOMMENDATIONS

- The Caltech fog water sampler does not bias the field fog water conductivity data through evaporative effects to the extent that has been suggested (factor of 3-4).
- This study should be repeated at lower temperatures (0 -4^{o}C) to insure that the lower effective flow rate caused by ice formation on the strings does not bias the data.
- The effect of lower liquid water contents should also be investigated using a different nozzle.
- More time resolved data should be collected during the early and late stages of fog episodes.
- Consideration should be given to the use of only one screen for the collection of fog water in the field.

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